Effect of Irrigation Treatments for Apple Trees on Water Uptake from Different Soil Layers

I. Levin², R. Assaf³, and B. Bravdo⁴
The Volcani Institute of Agricultural Research
Bet Dagan, Israel

Abstract. Six irrigation treatments consisting of replenishing the water extracted from the 0-60 cm or 0-120 cm layer, were applied to a 10-year-old apple orchard. The highest yield and fruit size were obtained by irrigating to 60 cm depth when soil moisture to this depth dropped to 40% available water during the 2 months of intensive fruit growth. During the rest of the season this treatment was irrigated to 60 cm whenever the 0-60 cm layer dropped to wilting point and to 120 cm whenever the 60-120 cm layer dropped to 60% available water. The relative water extraction from the 60-90 cm layer was the highest in this treatment. Increasing water uptake from layers below 120 cm by watering them was not effective. Climatic conditions favoring high rates of evaporation increased the relative contribution of layers deeper than 90 cm in all plots. The proportion of water loss from the 0-30 cm layer increased with the number of irrigations.

A widely used technique in orchard irrigation consists of replenishing the water extracted from the soil profile occupied by the roots. However this approach overlooks the fact that the water extractions along the soil profile is uneven and depends on root distribution and soil water tension. Data in the literature are not consistent. Veihmeyer and Hendrickson (4, 5) reported that root distribution of deciduous trees usually was such that uniform use of water occurred in the top 5-6 ft of the soil. Packer (3) found that the water uptake in 'Jonathan' apples growing in both clay and sandy loam soils was uniform along the profiles of the 0-60 cm layer. Goode (1) found that in apples growing on loamy sand, 60% of all the roots in the 75 cm profiles were in the upper 30 cm layer and 30% in the 30-60 cm layer. There were no differences in root distribution between the dry and wet treatment at 1 and 2 m distance from the trees and at a soil depth of 90 cm. The relative water uptake from all soil layers was correlated with the relative root density (2). In a preliminary survey on apples growing in clay loam soil, we found that in 16 days in September, 50% of the total water depletion occurred in the 0-30 cm layer, 20% in the 30-60 cm layer, and only 22% in the 60-120 cm layer. We attributed the poor water depletion below 60 cm depth to the commercial irrigation practice according to the average moisture content of the entire profile of 0-150 cm, and not according to the needs of each soil layer.

Our objective was to improve water uptake at soil layers deeper than 60 cm, expecting that this would increase yields. The irrigation treatments were planned to be applied whenever soil moisture content reached a predetermined level at each soil layer. This approach required a study of the relations between water uptake from different depths during the 2 years preceding the beginning of the experiment, since watering the deeper layers requires saturation of the entire profile. We learned that irrigating soil layers of 60 cm thickness were the most suitable for technical reasons although shallow layers would have been preferable.
Table 1. Plan of irrigation treatments on apples.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Available soil water before irrigation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 - 60 cm</td>
</tr>
<tr>
<td>1 Dry</td>
<td></td>
</tr>
<tr>
<td>2 Dry*</td>
<td>W. P. + 14 days&lt;sup&gt;z&lt;/sup&gt; 60</td>
</tr>
<tr>
<td>3 Medium</td>
<td>20</td>
</tr>
<tr>
<td>4 Combined. Wet (T&lt;sub&gt;6&lt;/sub&gt;) June 10 to Aug. 10 and dry (T&lt;sub&gt;2&lt;/sub&gt;) rest of season</td>
<td>80</td>
</tr>
<tr>
<td>5 Commercial&lt;sup&gt;x&lt;/sup&gt;</td>
<td>50% of 0 - 120 cm profile</td>
</tr>
<tr>
<td>6 Wet</td>
<td>40</td>
</tr>
</tbody>
</table>

<sup>z</sup>14 days after wilting point (W.P.) was reached.
<sup>y</sup>In 1969 this treatment was changed to same regime as T<sub>4</sub>.
<sup>x</sup>Common commercial irrigation practice in the Hula Valley.

Materials and Methods

Six irrigation treatments were applied by sprinkling to an apple orchard, cv. Calville de St. Sauveur on <i>Malus sylvestris</i> rootstock (commonly called 'Grand' in Israel), planted in 1958 at 4.0 x 5.5 m spacing, at Kibbutz Hulata in the southern Hula Valley. The site is 70 m above sea level. Average annual precipitation (limited to winter) is 400 mm. The average daily temp from May to September is 24.7°C and from December to February 12.4°C. The soil is brown clay grumusol, uniform throughout the 200 cm profile, containing 48% clay and 39% silt. The ground-water table was below 4 m throughout the summer. The field capacity (determined gravimetrically) is 27% (wt) in the 0-30 cm layer and 25% in the rest of the profile. The wilting point is 17%; bulk density, 1.42; and pH, 7.6.

Each treatment was applied to a plot of 4 trees with 2 border trees on each side, replicated 6 times in a randomized block design. Commercial sprinklers (Na'an 213) with 2.2 mm nozzles supplying 250 liters/hr were placed 5.5 x 6 m apart. These distances were adopted after a preliminary test in which cans were used to collect the water at different distances from the sprinklers. It was found that the coefficient of variation of water collected in the cans was 33% in an open field and 28.4% in the orchard.

Access tubes 2.4 m long were driven into the soil at 1.75 m from each tree for determination of the soil water by the neutron scattering method (Troxler, USA). This was followed in

![Fig. 1. Seasonal soil water content at 3 depths in 6 irrigation treatments (T) A, 1968; B, 1969.](image-url)
5 replications of each treatment, while the 6th plot contained 25 tubes located at 1 x 1 m distance inside the square created by the experimental trees. This plot provided more detailed soil moisture readings at different distances from the trunk. Soil water was determined at few intervals between irrigations. Evapotranspiration was determined by extrapolating the lines connecting the soil moisture values. The treatments consisted of replenishing the moisture deficit to field capacity in either the 0-60 cm or 0-120 cm layer of the soil profile (Table 1), after the moisture content had reached a predetermined level selected according to soil moisture determinations carried out during the 2 prior years. The orchard was sod cultivated prior to and during the experimental period as is common practice in the commercial orchards in the area. Sixty kg/dunam (1000 m²) ammonium sulfate was applied every year and 80 kg/dunam potassium chloride every 2 years.

Results

The number of irrigations was similar in both years, except in treatment 2 which was changed to duplicate treatment 4 in order to verify the effect of short-interval irrigation during the main period of fruit growth. There was no distinct relationship between the amount of water applied and the number of irrigations, since in wet treatments mostly the top 0-60 cm layer was irrigated. In 1968 irrigation was applied once to wet the 120-180 cm layer in all treatments, while in 1969 all irrigations were limited to wetting to a depth of 120 cm. Since the number of irrigations and the amount of water applied was determined according to the rate of water uptake, there were variations between the 2 years in the number of irrigations and in the amount of water applied.

The soil moisture content before each irrigation, as shown by the seasonal water extraction curves (Fig. 1), did not deviate

Fig. 1. (cont). Seasonal soil water content at 3 depths in 6 irrigation treatments (T) A, 1968; B, 1969.
greatly from the predetermined values in Table 1.

In treatment 1 (dry), the rate of water extraction decreased with depth. The difference was particularly pronounced at low soil moisture content. In the 60-120 cm layer the rate of water uptake decreased after the moisture content dropped to around 30%, while at the same time the top layer (0-60 cm) had already reached the wilting point. In the 120-180 cm layer the rate of water loss was very slow.

The rate of water uptake in 1968 was similar for treatments 1 and 2, although the latter received 6 irrigations; the former, only 4. In 1968 the water content of the 60-120 cm layer in treatment 2 did not drop below 60% available water (except for the first irrigation applied in May). The irrigations (to 1.2 m) were applied twice, on May 11 and June 30, but it is apparent from Fig. 2 that small variations in the water content occurred in the 60-120 cm layer whenever the top layer, 0-60 cm was irrigated.

In treatment 2 in 1969 there was considerable variation in water content in the 60-120 cm layer throughout the entire season. At the beginning and the end of the season, water uptake in treatment 2 resembled that in treatment 1, while in the middle of the season the short intervals increased the rate of water uptake in the top 0-60 cm layer. In the 60-120 cm layer the fluctuation was very small during this period, and water content was very close to field capacity. This was partially due to water drainage following the irrigations applied to the 0-60 cm layer. In the 120-180 cm layer there was a slow drop in the water content as the season advanced. Some water was added to
Table 2. Effects of irrigation regimes on yields of apples.

<table>
<thead>
<tr>
<th>Treat. no.</th>
<th>No. of irrig.</th>
<th>Water applied (mm)</th>
<th>Yield (kg/dunum)</th>
<th>% of large fruit2</th>
<th>1968</th>
<th>1969</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>690 630</td>
<td>6300x 6850x</td>
<td>28 32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>115 810</td>
<td>8400x 7450x</td>
<td>35 56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>1070 840</td>
<td>8190 8830</td>
<td>55 44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>1090 830</td>
<td>8510 9110</td>
<td>63 54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>13</td>
<td>1120 1040</td>
<td>7730 8970</td>
<td>61 37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>23</td>
<td>1390 1290</td>
<td>9460 8830</td>
<td>60 56</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S.E. 271 287

2Diameter of 6.5 cm and up.

In treatment 2 the same as treatment 4.

3Significantly different from treatments 3, 4, 5, and 6 at p = 0.05.

this layer whenever the upper layers were wetted.

In treatment 3 the 0-120 cm layer was irrigated to its full depth only once (May 1968) although some contribution of water draining from the upper layer was apparent. The rate of water uptake from the 120-180 cm layer in this treatment was particularly slow.

The seasonal amount of water used in treatment 4 (Table 2) was smaller in 1968 than in 1969. This treatment extracted more water from the 60-120 cm layer in 1969 than treatment 2. However, the seasonal amount of water was similar in both treatments in 1969 (810 and 830 mm).

In treatment 5 all irrigations were applied down to the 120 cm layer. The irrigations were applied at predetermined dates which corresponded to the commercial practice in the area. Water uptake here was also higher in 1968 (Table 2).

In treatment 6 the higher rate of water uptake from the top 0-60 cm layer required 100 mm more water in 1968 than in 1968. The moisture content in the 60-120 cm layer was around field capacity throughout both seasons. The small amounts of water drained to the 120-180 cm layer was sufficient to maintain high water content throughout the season in both years.

Most of the water extracted from the 180 cm profile was extracted from the 0-30 cm layer in all treatments (Fig. 2). The relative water extraction from the 0-30 cm layer varied from 70% in the dry treatment to 55% in treatment 6. For the 0-60 cm layer it varied between 25% in treatment 1tr to 78% in treatment 6. The water loss from the 120-180 cm layer varied between 20% in the dry treatment and 7% in the wet ones.

Water was extracted more intensively in 1968, and relatively more water was extracted from the deeper layers than in 1969.

Discussion

We succeeded in maintaining, within a range of 5 to 10%, the predetermined levels of available water. In spite of considerable differences in amounts of water and in number of irrigations applied, only treatments 1 and 2 differed significantly in yield from the others. This difference was due mainly to the effect on fruit size in 1968; differences in yield and size of the fruit. The number of the irrigations and amount of water applied cannot serve as a schedule for irrigation practices, since they vary due to climatic and plant factors. The following points support this conclusion:

a) In 1968 treatments 1 and 2, which received 4 and 6 irrigations with a total of 690 mm and 815 mm of water, respectively, showed no significant difference in yield and only a slight difference in fruit size.

b) By making treatment 2 the same as treatment 4 in 1969, the difference in water applied between treatment 1 and treatment 2 increased from 125 mm in 1968 to 180 mm in 1969, mainly due to watering the 0-60 cm layer. This resulted in approx 60% increase in the percentage of large fruit accompanied by an increase in yield of 1000 kg/dunam in 1969.

c) Treatments 3 and 5 were irrigated at almost identical intervals. However, treatment 5 was irrigated repeatedly to replenish the water in the 60-120 cm layer, whereas in treatment 3 this layer was irrigated only when its moisture content reached the predetermined level of 60% available water. Consequently the total amount of water applied in treatment 5 exceeded that for treatment 3 by 50 mm in 1968 and by 200 mm in 1969. Nevertheless, yield and fruit size were similar.

d) Treatment 6 and treatment 4 were irrigated similarly only during the main period of fruit growth (from June 10 to Aug. 10). The yield and fruit size in the 2 treatments did not differ, although treatment 6 received double the number of irrigations and 300-460 mm more water than treatment 4. This emphasizes the importance of the water regimes during the stages of fruit growth.

The pyramids shown in Fig. 2 are wider at their lower parts in 1968 than in 1969 in all treatments except treatment 5. This may be attributed to the faster uptake in 1968. However, treatments 1 and 2 in 1968 and 1969 and treatment 4 in 1968 extracted a higher percentage of the total evapotranspiration water from the deeper layers in comparison to the rest of the treatments. In 1969 the relative water uptake in treatment 4 was high in the 30-90 cm layer, and in particular in the 60-90 cm layer, which was also high in 1968. It may well be that the success of this treatment, as reflected in yield and fruit size, is connected with this pattern of water extraction. The relative water extraction of the 0-30 cm layer increased with the intensity of irrigation: it varied from 30% in the “dry” treatment to 55% in the “wet” treatment. Contrary to this, there was an increase in water uptake from layers deeper than 90 cm with decreasing intensity of irrigation. The 30-60 cm layer was less subjected to variations in all treatments. Its relative contribution amounted to about 23% of the total water extracted. Our objective to increase the water uptake from soil layers deeper than 60 cm was met in treatment 4. As expected this treatment also increased yield and fruit size.

Literature Cited


After applying 1 irrigation to wet the 120-180 cm layer in 1968, we decided to discontinue wetting to this depth. We realized that the efficiency of watering this layer in increasing growth and yield is doubtful, since wetting to this depth requires an extra 60 mm of water per irrigation (compared with irrigation to 120 cm), and does not alter the moisture content of the upper layers.

We concluded that the water regime in the different layers during different stages of growth throughout the season affects yield and size of the fruit. The number of the irrigations and amount of water applied cannot serve as a schedule for irrigation practices, since they vary due to climatic and plant factors. The following points support this conclusions:

a) In 1968 treatments 1 and 2, which received 4 and 6 irrigations with a total of 690 mm and 815 mm of water, respectively, showed no significant difference in yield and only a slight difference in fruit size.

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Inheritance of Resistance in *Phaseolus vulgaris* to *Uromyces phaseoli typica* Brazilian Rust Race B11 and of Plant Habit

Eliane Augustin, D. P. Coyne, and M. L. Schuster

University of Nebraska, Lincoln

Abstract. A new method of inoculation of bean seedlings with urediospores of *Uromyces phaseoli typica* Arth. produced an even distribution of numerous pustules on the leaves. A suspension of urediospores in Freon-113 was sprayed on both surfaces of the primary leaves. The plants were then placed in a moist chamber for 18 hr under a low light intensity of $2 \times 10^{-5}$ einsteins cm$^{-2}$ sec$^{-1}$, before being transferred to the greenhouse. In screening tests the cvs. Great Northern 1140 and Kentucky Wonder Wax No. 765 were resistant to Brazilian race B11; 'GN 1140' showed the highest grade of resistance. Segregation for the reaction to rust race B11 in the F2 generation in crosses between the resistant cv. GN 1140 and 4 susceptible lines indicated that a major gene controlled the reaction with the resistant reaction dominant. The symbol $R_{B11}$ was assigned to the dominant allele. Linkage was not detected between genes controlling plant habit and disease reaction.

Brazil is the world’s largest producer and highest consumer of dry beans. Dry beans (*Phaseolus vulgaris* L.) are the primary protein source for most people of Brazil. Rust caused by *Uromyces phaseoli typica* is an important disease of beans, accounting for reduction of yields in Brazil and in other countries (12).

Variation in pathogenicity of the fungus was first described by Harter et al. (7) in 1935 and since then further variation has been noted (1, 2, 5, 6, 11, 12). There is limited information on the inheritance of the reaction to rust in beans (10, 11). Qualitative genetic control of the disease reaction has been previously reported (10, 11).

A knowledge of the physiologic races, the environmental factors that affect infection, and effective inoculation methods is necessary in a breeding program for rust resistance. Miller (8) reported that Freon-113 was a good suspending medium for the dispersal of urediospores of stem rust of wheat caused by *Puccinia graminis tritici* Eriks. and E. Henn, and suggested that it could be used as a dispersal medium for spores of other fungi, after toxicity to the spores was determined. Wei (9) noted that light was essential for bean rust infection but no measurement of light intensity was recorded.

Sixteen bean rust races were identified in southern Brazil (2, 6). 'CUVA 168-N', one of the most important dry bean cultivars in Brazil, is resistant to all the known rust races except race B11 (1). We report a comparison of inoculation methods with bean rust, identification of sources of resistance to Brazilian rust race B11, inheritance of the reaction to this race in several crosses, and inheritance of plant habit.

Materials and Methods

Inoculation methods. Since the rust fungus is an obligate parasite, abundant spore material was maintained by culturing it on the susceptible ‘Dark Red Kidney’ in the greenhouse. We investigated the effect of a combination of 3 light treatments in dew chambers and 2 methods of inoculation on rust development in 'Dark Red Kidney'. Light entered the chambers through the roof. The 3 light treatments in the chambers were: low light intensity, $2 \times 10^{-5}$ einsteins cm$^{-2}$ sec$^{-1}$, for 18 hr; darkness for 6 hr and then high light intensity, $3 \times 10^{-3}$ einsteins cm$^{-2}$ sec$^{-1}$, for 12 hr; and high light intensity, $3 \times 10^{-3}$ einsteins cm$^{-2}$ sec$^{-1}$, for 18 hr. A light meter developed by Briggs (3) was used to record light intensity. The temp in the dew chamber was 18°C. The experimental design was a randomized block complete with 3 replicates.

Seeds were planted in 3-inch clay pots filled with a mixture of equal parts of sand, peat moss, and vermiculite. The seedlings

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2 Graduate student and Professor, Department of Horticulture and Forestry; and Professor, Department of Plant Pathology, respectively. The present address of the senior author is IPEAS, Setor De Fitopatologia, Pelotas, R. S. Brazil.